

THE ORIGIN OF WARREGO VALLES: A CASE STUDY FOR FLUVIAL VALLEY FORMATION ON EARLY MARS. Virginia C. Gulick^{1,2}, James Dohm³, Ken Tanaka³, Trent Hare³, ¹MS 245-3, Space Sciences Division, NASA-Ames Research Center, Moffett Field, CA 94035, *email*: gulick@mawrth.arc.nasa.gov, ²also at Dept. of Astronomy, NMSU, Las Cruces, NM, ³U.S.Geological Survey, Flagstaff, AZ 86001.

Warrego Valles (Fig. 1) is perhaps the most "famous" of all Martian valleys as it appears as frequently in undergraduate astronomy textbooks as it does in scientific talks. It is almost universally cited as evidence for rainfall during a warm, wet early Mars. Thus understanding the origin of Warrego is central to answering the question, "*How did the ancient valley networks form?*" Did they require a substantially different climate with global temperatures above freezing or could they have formed under less clement climatic conditions involving geothermal/hydrothermal processes as both sources of heat energy and drivers of ground-water outflow.

Warrego Valles lies along the southern edge of the Thaumasia plateau. It formed in the southern highlands but tectonic fractures dated by Tanaka and Dohm [1] to be early Hesperian cross cut and have in turn been cross cut by the valley system [2,3]. This implies that Warrego Valles was still actively forming well into the Hesperian.

Pieri [4], who completed an early systematic study of the valley networks on Mars, concluded that the digitate pattern formed by this valley system is most consistent with formation by ground-water sapping. This finding is in contrast to the often cited evidence for a rainfall origin [5]. Gulick [2,3] also questioned the rainfall origin. She concluded that regardless of whether the valley system formed by surface runoff or ground-water sapping, the lack of similar erosion along adjacent edges of the Thaumasia plateau

for hundreds to thousands of kilometers is difficult to understand if the source of the water was rainfall.

Gulick [2,3,6] and Gulick et al. [7] argue that the localized erosion pattern at Warrego is more consistent with a localized water source. Two possibilities are hydrothermally driven ground-water outflow [2,6] and melting of a snowpack by locally high geothermal heat flow [2,7]. The radial drainage pattern of Warrego Valles may provide insight as to its formation as it appears centered approximately on a 35 km diameter impact crater [2,3,6]. However, a closer study reveals that the valleys have formed on and have delineated a much larger region of uplift (Fig 2).

A possible cause of the uplift may have been from a magma intrusion in the subsurface or incipient volcanic activity [2,6,7]. Both the subsurface magmatic event and the formation of an impact crater would have resulted in the formation of vigorous hydrothermal systems. We have mapped in detail the Warrego region with the goal of understanding how the possible interaction of tectonic and volcanic processes may have led to fluvial valley formation. In addition, Dohm *et al.* [8] and Tanaka *et al.* [9] have concluded based on their 1:15,000,000 geologic map of the Thaumasia Quadrangle, that valley formation within the entire Thaumasia region is consistent with areas of inferred past hydrothermal activity.

While both the impact crater and the hypothesized magmatic intrusion may have triggered hydro-

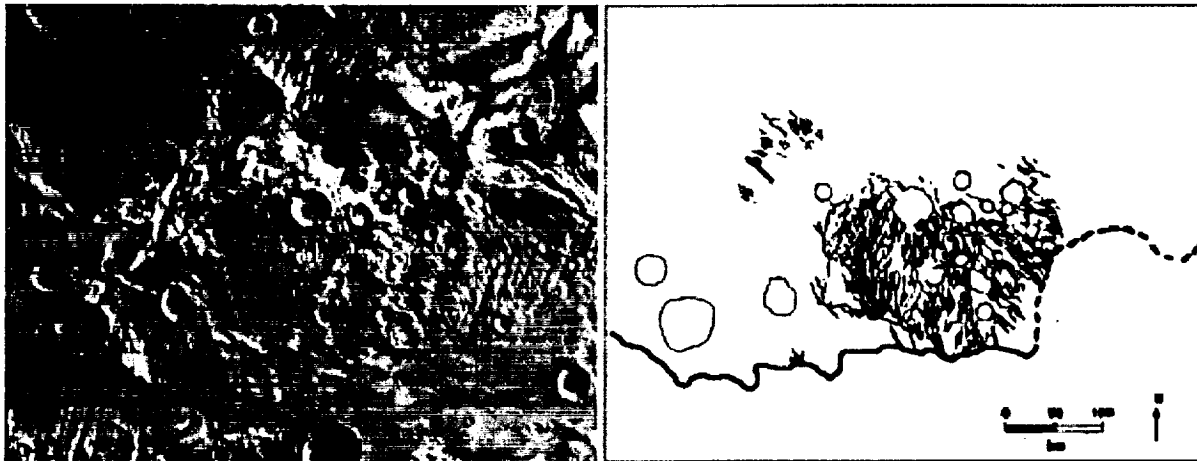


Figure 1. Warrego Valles (left) and sketch map (right). The boundary between the southern edge of the Thaumasia Plateau and the adjacent lowlands is shown as a heavy line, dashed where approximate. Note how the valleys cluster over an area about 200 km across.

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thermal circulation and produced fluvial valleys, the magmatic intrusion is more likely responsible.

The large impact crater from which the valleys seem to radiate is approximately 35 km in diameter. From scaling relations in Melosh [10], we estimate that depending on the impact velocity, the formation of this impact crater would have produced approximately 12 km³ of impact melt, which is uncertain to about a factor of 2. Distributed over the final crater area, this would produce a melt pool approximately 10 m deep. Such a thin melt lens would cool quickly by conduction. Terrestrial analog studies [2,3] suggest that highly integrated tributary valley systems such as Warrego require liquid water to flow on or near the surface for periods of several 10⁵-10⁶ years or more. Indeed Gulick *et al.* [11] estimated that only impact craters greater than 100 km in diameter would produce sufficient impact melt to drive a hydrothermal system capable of forming fluvial valleys [6]. There is no such impact crater in the immediate vicinity of Warrego Valles.

The region of uplift upon which Warrego sits is approximately 100 km in radius. An underlying magmatic intrusion with only 10% of the radius would still have a volume in excess of 300 km³, even if it were only 1 km thick. A thicker intrusion, as seems likely given the 5 km rise across the boundary, could easily have a volume in excess of 1000 km³.

Gulick [2,6] finds that hydrothermal systems associated with magmatic intrusions greater than 500 km³ can easily drive sufficient ground water outflow to form fluvial valleys. She estimates that a 500 km³ intrusion will produce approximately 40,000 km³ of outflow over 10⁶ years. The volume of the Warrego valleys is estimated to lie in the range of approximately 400 to 1500 km³. Assuming a conservative ratio of water to removed material of 1000:1, a reasonably-sized magmatic intrusion beneath Warrego Valles could provide sufficient ground water outflow to drive fluvial valley formation.

In summary, although Warrego Valles is one of the best examples of a well integrated fluvial valley system that formed early in the geological history of Mars, the lack of similar erosion elsewhere along the edge of Thaumasia plateau is not consistent with a formation by rainfall. Instead the radial pattern of this valley system centered on a region of localized uplift argues for a more localized water source. We conclude that this uplift was most likely the result of a subsurface magmatic intrusion and that the estimated volume of this intrusion is sufficient to cause enough hydrothermal ground-water outflow to form the valley system. A possible alternative to this scenario is hydrothermal ground-water outflow combined with a melting snow pack.

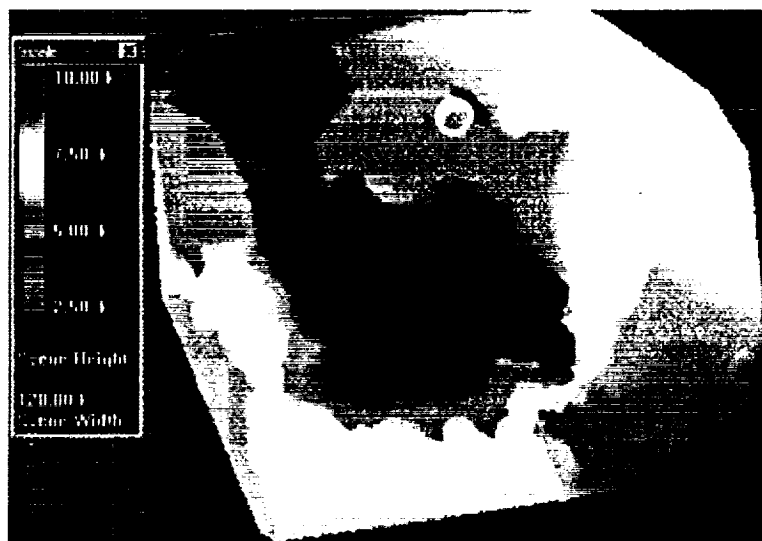


Figure 2. Digital elevation model of region surrounding Warrego Valles. Note that the rise from the mouth of the valley network to its source regions is approximately 5 km.

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